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Technical Lesson 2

UNITS OF ELECTRICAL MEASUREMENTS AND SYMBOLS

In the preceeding lessons we built up a background for our future work. From this point on we will deal more specifically with the subject of radio and electricity. Accordingly, we will first define the fundamental units of measurement which form the basis of electrical computation and later the electrical units and terms which are in common use in radio.

The three fundamental units of measurement are:

- (1) the centimeter, or unit of length,
- (2) the gram, or unit of mass,
- (3) the second, or unit of time.

These three quantities are combined and expressed below in a simple relation known as the centimeter-gram-second, or C.G.S. system.

The C.G.S. unit of velocity is the kine, representing a distance of one centimeter covered in one second.
 $1 \text{ centimeter} = 0.01 \text{ meter} = 0.3937 \text{ inch.}$

The C.G.S. unit of force is the dyne, representing the force required to move a mass of one gram one kine per second.
 $1 \text{ gram} = 1/28\text{th of an ounce.}$

The C.G.S. unit of work or energy is the erg, representing the work accomplished by a force of one dyne working over a distance of one centimeter.

In this lesson we give the definitions of the most important electrical units with simple problems to explain their meanings. These units are used repeatedly throughout our course and, therefore, they must be learned by the student. If these units are learned at the start then no difficulty will be encountered in the work before us.

ELECTRICAL UNITS

THE VOLT is the unit of electrical pressure. This pressure is known as the "electromotive force" and, also, as "difference of potential". Electromotive force is abbreviated by the letters (E.M.F.) or (e.m.f.).

One volt is defined as the amount of electromotive force necessary to cause a current intensity of one ampere to flow through a circuit having a resistance of one ohm.

In electrical practice you will hear references made to this unit by any one of the following names: Volt, Voltage, Electromotive Force, Pressure or Difference of Potential, all of which have the same meaning. The unit volt is denoted by the symbol (E).

In an electrical circuit we express the amount of the electromotive force as a certain number of volts. To illustrate the proper use of the terms "e.m.f." and "volts" let us consider the simple circuit drawn in Figure 1 where a 6 volt battery is connected to a 6 volt lamp. When speaking about the pressure in this circuit it would be the customary thing to say: "The e.m.f. of 6 volts, applied to this circuit by the battery, forces a certain amount of current through the filament of the lamp, thus causing it to light."

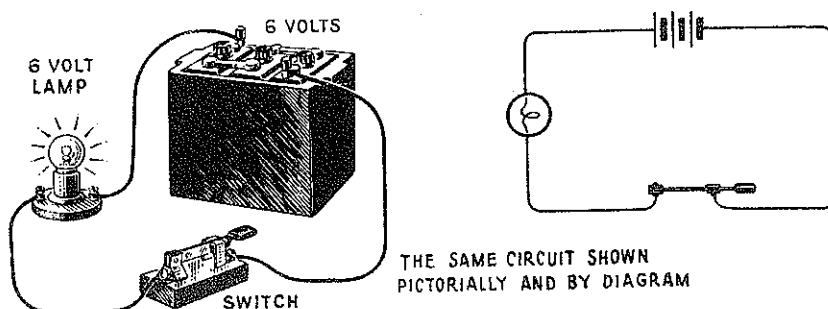


Figure 1

Electrical pressure is analogous to water pressure. To illustrate this let us suppose you connect up your garden hose to a faucet and open the valve. Providing there is water supply available in the mains we know that water will run through the hose. The pressure in the pipes was necessary in order to get this flow of water. Just how water pressure in pipes is obtained in our homes and buildings should be quite obvious to most anyone since there are practically only two sources; one source is the result of mechanical work done by a pumping machine of some type, while the other is the result of natural gravity provided by a head of water, or water supply originating at some level higher than the outlet where the hose is attached.

To point out the idea that pressure is always essential before a movement or motion of any kind can be produced we have shown a small tank partly filled with water in sketch (A) of Figure 2. Notice that to the bottom of the tank there has been connected a short pipe, bent into a U shape, the open end of which is arranged exactly level with the tank connection.

The valve acts in a manner similar to a switch in an electrical circuit in controlling the flow. If the valve in the pipe is closed the water pressure is not utilized although the pressure is always present by reason of the height and volume of water in the tank. But, if we open the valve the pressure will immediately act and water will flow through the pipe and gush out at its open end. The flow will continue just so long as there is any water in the tank or any pressure. Finally when the tank is emptied it will be seen that the pipe still holds a quantity of water which does not flow out of the open end because both ends of the pipe are level, as shown in sketch (B). This result shows that while the water remaining in the pipe has a potential force due to its own weight, yet it cannot be made

use of in this case. Thus, we see that it requires a difference of pressure level to obtain force by which the water may be made to flow even though water may be at hand. However, by merely bending the open end downward, as in (C), the water confined in the pipe will begin to flow out, since we have set up a condition where the force due to the weight of water is now acting. The higher the water level in the tank the greater will be the available pressure.

Although we can see the water we cannot see the "pressure". Nevertheless, it is easy to measure water pressure in pounds with a suitable pressure gauge. When we refer to pressure in the electrical sense, we also deal with an unseen force which may be generated in one of several ways. We

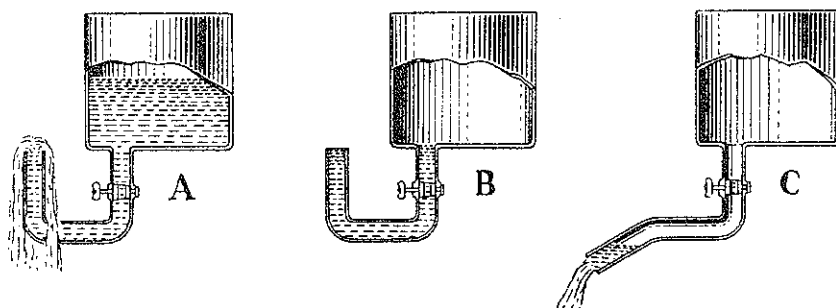


Figure 2

know how to regulate the intensity of this electrical pressure according to certain requirements so that it may be applied to a circuit to set up a flow of current. It is also easy to measure electrical pressure by means of a suitable instrument, called a "voltmeter". Several common sources of electrical pressure are batteries, generators, electromagnetic induction and electrostatic induction.

THE AMPERE is the unit of electric current; it represents a certain amount of current flowing at a given rate.

One ampere is defined as the intensity (or strength, or value) of the current that will flow through a circuit whose resistance is one ohm, when the applied electromotive force is one volt.

The following is another definition of the unit of current strength, based on the amount of chemical decomposition taking place in a given period of time, and stated in terms of quantity and rate of flow. "One ampere is that steady flow of electric current which when passed through a standard solution of nitrate of silver in water, will deposit silver at the rate of 0.001118 gram per second."

The quantity of electricity is measured by the unit "coulomb". Although this unit is defined in a subsequent paragraph let us at this time show the relation between "coulomb" and "ampere" as follows: "When one coulomb of electricity passes a given point in a circuit, every second of time, one ampere of current is said to flow". Hence, if 2 coulombs of electricity pass a given point in a circuit per second the strength of the current is 2 amperes. In a given circuit, therefore, to find the total quantity of electricity expressed in coulombs we must take the product of the current

in amperes and the length of time in seconds that the current flows. Note: The underlined definition of an ampere is the one that should be learned for our practical work.

Current is denoted by the symbol (I) and is measured by an instrument called an "ammeter".

Again refer to the drawing in Figure 2 to be sure that you have a clear understanding of the difference between "quantity" and "rate of flow". Water flowing through a pipe at the rate of a certain number of gallons per minute can be compared to current in amperes passing through a circuit. In a water system "gallons" represents the quantity and "gallons per minute" the total amount for a given time, or rate of flow; whereas, in the electrical circuit "coulomb" is the quantity and "amperes" is the rate of flow of a given quantity.

An important point to be mentioned in this discussion is that throughout the whole length of the pipe there are oppositions set up which prevent a free movement of the water. These oppositions are due principally to friction by contact of the water with the inner walls of the pipe, bends in the pipe and the length and size, or cross section, of the pipe. In any of its forms, opposition must be met and overcome by the pressure before water flows and, of course, the oppositions will govern to some extent the amount of water that flows in a given time under a given pressure. It is easy to see that any opposition presented by the pipe itself will retard the water flow.

This opposition is comparable to that which is present at all times in electrical circuits because the wires or other metallic parts do not permit a free movement of electrons, or current, but rather, the current is forced to flow through the materials used to construct the circuit under the applied voltage. Each different kind of metal has its own specific resistance. For instance, current flows more readily through silver than through copper, and more readily through copper than iron. Thus, if we have two circuits consisting of the same length and cross-section of wire, and if one circuit uses copper wire and the other iron wire, and if exactly the same voltage is applied to both circuits it will be found, under these conditions, that about six times as much current will pass through the copper wire as compared to the iron-wire circuit. This is because the relative resistance of copper is 1.075 as compared to 6.37 for iron. In the case of the electrical circuit this opposition of the material itself, which governs to a large extent the intensity of the current flow, is known as the "resistance". This subject is again discussed under the unit of resistance, the ohm.

An AMPERE-HOUR is the unit in general use in battery charging service; it represents a continuous flow of current of 1 ampere for 1 hour.

THE OHM is the electrical unit of resistance. Resistance is the natural opposition which all materials offer to the flow of electronic current, and since this opposition is inherent in all matter it must be overcome by the electromotive force before current will flow.

One ohm is the amount of resistance of an electrical circuit when an electromotive force of one volt is required to force a current of one ampere through it.

The following is a definition of the unit resistance based on a physical standard: One ohm is the amount of resistance that would be offered to a steady flow of electric current by a column of mercury of uniform cross-section, 106.3 cm. long, 14.4521 grams in weight at a temperature of 32 degrees Fahrenheit, or 0 degrees Centigrade. (Note: One centimeter is a little less than a half inch. One ounce is equal to 28 grams.)

The ohm is denoted by the symbol (R) and is named after the German scientist George S. Ohm. He was responsible for recognizing the relation existing between the "voltage", "resistance" and "current" in all electrical circuits and formulating this relation into what is probably the most important and widely used law in electricity, known as "OHM'S LAW".

When a conductor has an exceptionally high resistance we use the unit "megohm". For conductors having a very low resistance we use the "microhm".

One megohm equals one million ohms.
One microhm equals 1/1,000,000th of an ohm.

THE COULOMB is the unit of electrical quantity used to express the total quantity of electric current passing through a circuit in a stated time.

One coulomb is the quantity of electricity that will flow in one second through a circuit having a resistance of one ohm when the applied e.m.f. is one volt.

We are now dealing with "quantity" in electricity in about the same way that ordinary standards, a pound or gallon for instance, are used to measure supplies such as sugar, milk, etc. Thus, if we wish to know the number of "coulombs" or "quantity of electricity" passing through a circuit in a given time we must multiply the number of amperes by the number of seconds the current continues to flow.

The following example shows how to apply this rule: Suppose the rate of current flow for a particular circuit is 8 amperes and the current continues to flow steadily for 4 seconds. The total quantity of electricity passed will be 8×4 or 32 ampere-seconds, or 32 coulombs of electricity. Also, if 2 amperes flow for 16 seconds we would have 32 ampere-seconds or 32 coulombs.

The unit "coulomb" is also applied in electrostatics with reference to placing an electrostatic charge in a condenser and in this usage it is defined as follows: "One coulomb is the quantity of electricity necessary to raise by one volt the difference of potential between the plates of a condenser whose capacitance is one farad."

The coulomb is denoted by the symbol (Q).

THE HENRY is the unit of inductance. Inductance is a certain property possessed by every electrical circuit which establishes an electromagnetic field about its conductors and windings (coils). Inductance is also applied to the peculiar property of all conductors and windings (coils) which tend to oppose any current change produced by a circuit within itself by virtue of the changing magnetism which is set up whenever current varies or tends to vary in strength. The effect is pronounced in any circuit in which the

current is continually changing intensity, as for example, in a circuit carrying pulsating direct current or alternating current. The net result of inductive effects is the generation of a second e.m.f. separate from the applied e.m.f. which causes the current to flow.

This property of "inductance" exists in all portions of an active circuit because the electromagnetic lines of force (flux) set up by the current will vary in magnitude according to every change in current intensity and these magnetic lines are continually acting upon the very wires (or conductors and coils) which comprise the circuit. The term "self-inductance" is commonly used to express this peculiar property exhibited by a circuit due to the action of its own magnetic lines upon itself. The tendency of a circuit to prevent changes in current intensity and spoken of as the "self-inductance" of a circuit, as just mentioned, represents one kind of opposition and it must not be confused with a circuit's "resistance".

Resistance is always present whether the current varies in strength or whether it flows steadily. However, "inductance effects" are not present in a circuit when a steady direct current flows, for in this case the magnetic lines are also steady and consequently do not act upon the conductors.

A circuit is said to have an inductance of one henry when an electromotive force of one volt will be induced in the circuit by a current varying at the rate of one ampere per second.

The letter (L) is the symbol used to denote inductance.

THE FARAD is the unit of electrical capacity and is abbreviated "fd". This unit relates to the amount of charge that can be stored up in a condenser in electrostatic form under a given e.m.f. measured in volts.

A condenser is said to have a capacitance of one farad if the potential difference between its plates will be raised one volt by a charge of one coulomb.

From this definition we see that a condenser when connected in a circuit and supplied with voltage will store up a definite amount of electricity in static form.

The farad is considerably too large to be applied in practical work. We therefore have two sub-multiples of the unit in common use. They are:

Microfarad (abbreviated mfd. or μ fd.)

Micro-microfarad (abbreviated mmfd. or $\mu\mu$ fd.)

One microfarad is equal to one-millionth part of a farad.

One micro-microfarad is equal to one-millionth part of a farad again subdivided into a million parts; that is to say, a micro-microfarad is one-millionth of one-millionth part of a farad.

EXAMPLE. Either unit, microfarad or micro-microfarad, may be used to express a certain numerical value according to one's own preference. As a rule values in the order of 1000 mmfd. and higher are expressed in

microfarads (mfd). Here are a few examples of how a value may be written in terms of either unit:

1 mmfd. = 0.000001 mfd.
 250 mmfd. = 0.00025 mfd.
 1000 mmfd. = 0.001 mfd.

A simple condenser is shown in Figure 3. It consists of a thin piece of suitable insulating material, such as mica, on either side of which is glued a sheet of tinfoil. The tinfoil sheets are called the "plates" and the mica the "dielectric". If two wires are connected from a source of voltage to the respective plates the e.m.f. thus provided will cause an electrostatic charge to be stored up by the mica. In Figure 4, the dry cell of 1.5 volts causes a difference of potential of 1.5 volts to be set up between plates "A" and "B" of the air type condenser; the electrostatic lines in this case are stored up in the air but in Figure 3 they are stored in the mica. The condensers in Figures 3 and 4 are called fixed condensers because no provision is made to alter their capacitances.

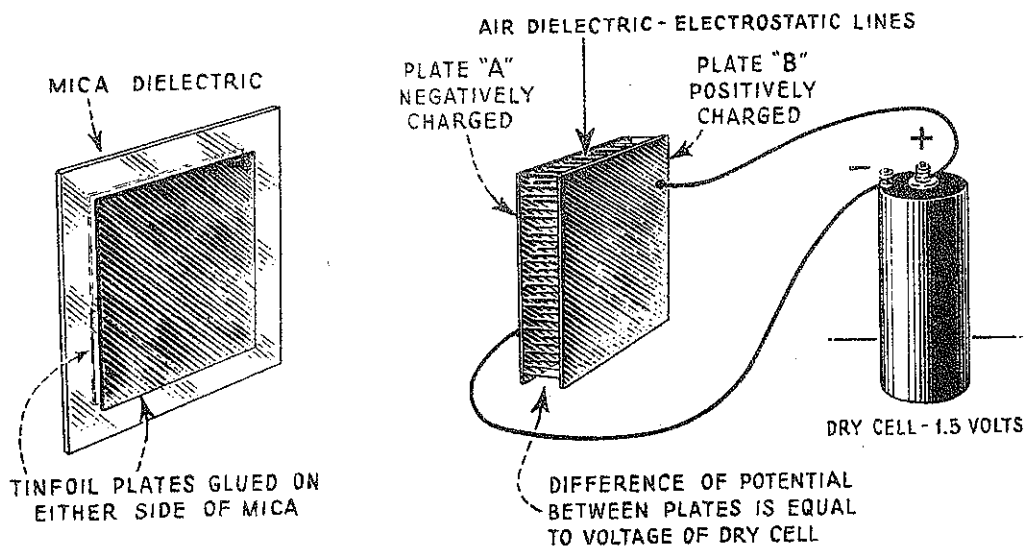


Figure 3

Figure 4

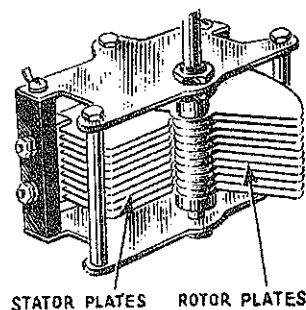


Figure 5

The multi-plate variable air type condenser in Figure 5 consists of a set of fixed and movable plates; this type is in general use in radio work for tuning purposes. The capacitance of this condenser is varied by rotating one set of plates, which acts to change the effective relationship between both sets of plates. The dielectric medium, which possesses the property of setting up electrostatic lines of force in a condenser of this kind, is the air which separates the plates. We will explain later how the particular kind of dielectric used, whether it be air, mica, paper or any other suitable material, has an important bearing upon the amount of charge the condenser will take on. The dielectric material also governs the amount of voltage that can be applied to the condenser without placing the insulating qualities of the dielectric under an excessive strain that would eventually result in a breakdown.

Capacity is designated in all of our writings and formulas by the letter (C).

ELECTRICAL WORK AND POWER. In our radio subjects we deal considerably with work and power. Through experience we find that very often the terms, force, power, energy and work are not thoroughly understood by everyone. To avoid any confusion between these terms we will explain their meanings in the following paragraphs, also giving a practical example of their use.

There are different kinds of force that will produce work when properly directed. For instance, we apply muscular force whenever we exert ourselves in the performance of certain tasks. Also, we have mechanical force derived from various types of motors and engines which may be operated with compressed air, gas, water, steam, gasoline and so on. There is also chemical force and electrical force. Other examples of force could be cited, but electromotive force is the force most frequently dealt with in our work. It will be repeatedly mentioned that an electromotive force, when properly applied, will cause or tend to cause a flow of electrical current.

FORCE. Force is an unseen agent which acts to cause some change in the existing motion of a body, or mass, or it may cause a change in direction of motion, or it may in some cases alter the physical shape of the body acted upon.

At this time let us review a few of the possible conditions relating to force. If a body is at rest and force is applied it will tend to set the body in motion; or if the body is already in motion a force may be applied in such a way as to cause the body to accelerate (move faster), or slow down, or perhaps come to a complete stop; or if a body is moving in a certain direction a force applied in some other direction will tend to cause the body to change its original course of direction.

It is to be understood that force does not always produce motion. This is a fact with which you are perfectly aware. For a simple illustration consider what would happen if you pushed against the side of a house with all your strength; you know that the energy expended would not result in the house being moved regardless of how hard you may have worked to accomplish this purpose. These natural laws are true in the case of electricity; an electromotive force does not in every case act to cause a movement of current but it tends to do so. Thus, it may be said that a force acting over a distance or through space is a factor of work but the action does not necessarily produce motion.

THE JOULE is the unit of electrical energy or work.

One joule represents the amount of work performed or energy expended, including that consumed in generating heat, when an electromotive force of one volt is applied to a circuit and a current of one ampere flows for one second of time.

We can express electrical work as the product of the "electro-motive force" in volts and the "quantity of current" in coulombs. Now, since an ampere is equal to one coulomb of electricity multiplied by a time period of one second, then this entire relation can be stated as follows:

$$\text{ELECTRICAL WORK (JOULES)} = \text{VOLTS} \times \text{AMPERES} \times \text{SECONDS}$$

The symbol (J) is used to denote the joule.

WORK. Work is performed whenever a force overcomes opposition, or resistance in causing a body upon which it acts to be set into motion. The amount of work done can be conveniently measured whether it is the result of mechanical, chemical, electrical or heat effects. Work, therefore, is done whenever energy is expended. This statement, no doubt, is plainly obvious to everyone and is intended to point out the fact that to do work does not necessarily mean that a weight must be lifted. For instance, work is done by compressed air acting upon a piston in a rivet machine; an explosion of a charge of gasoline vapor acting on one or more pistons provides the power in a gasoline motor for use in boats, automobiles and so forth; steam engines utilize the expansive force of steam on the heads of large pistons as a source of power. Steam may be used in a plant to drive electric generators which are in turn used to supply light, heat and power. We could go on indefinitely citing examples of how power is obtained to do different kinds of work.

A simple illustration of mechanical work is one in which a team of horses are in action, exerting energy in pulling up a very heavy weight by means of suitably arranged pulleys and lines.

An illustration of electrical work is where an electric flatiron is connected to a 110-volt house-lighting circuit. The work or energy expended in the electrical case is represented by the heat developed in the coils, called heating element, mounted within the iron. In order for this work to be done successfully we know that the voltage on the line was effective in overcoming all the oppositions of the circuit, with the result that a certain value of current was forced through the coils. This teaches us how electrical energy is transferred into heat energy.

The total amount of work done is calculated by multiplying the amount of a force and the distance through which it acts (or is applied) in overcoming resistance which results finally in a transference of energy from one form to another.

The accomplishment of a certain piece of work is independent of time. That is to say, it may require different amounts of time, as for instance a day, a week or perhaps longer to complete a given work. When the element of time is reckoned along with the work we must make reference to the term power.

POWER. Power is the time rate of doing work. It represents both the expenditure of a certain amount of energy and the length of time during which it is maintained. Since the term power includes the element of time we must not confuse it with the total amount of work actually performed.

The relation of "power", "work" and "time" can be set down as follows:

$$\text{POWER} = \frac{\text{WORK}}{\text{TIME}}$$

THE WATT is the unit of electrical power. From a little consideration of the three explanations previously given in regard to the joule (or unit of work), and the ampere (or the unit of current), and the volt (or unit of pressure) it is evident that the amount of "power" in any electrical circuit must be a combination of these three factors.

Thus, one watt is defined as that unit of power equivalent to one joule divided by one second. This relation may be written as follows:

$$\text{WATTS} = \frac{\text{JOULES}}{\text{SECONDS}}$$

Now we already know that a joule is the amount of work resulting when one ampere of current is maintained for one second under an applied e.m.f. of one volt. Therefore, combining this relation into one expression we have the well-known watts formula:

$$\text{WATTS} = \text{VOLTS} \times \text{AMPERES}$$

The watts formula expressed immediately above is for a direct current circuit. The same formula is repeated below but using the electrical symbols.

$$W = E \times I$$

It is clear that if we wish to ascertain the number of watts of power in a direct current circuit, or in the parts which form the circuit, we have simply to multiply the volts by the amperes. However, in our lesson on alternating current (a-c) we will learn that another factor, called power factor, enters into the computation of the wattage of an alternating current circuit or its parts.

The power or watts formula for an alternating current circuit is:

$$W = E \times I \times \text{POWER FACTOR}$$

The following definition of a watt should be learned:

One watt is the power expended when one ampere of current flows steadily through a circuit under a pressure of one volt.

The symbol (W) is used to denote the watt as used above in the formulas.

A practical example is worked out below showing how to find the wattage of a simple circuit.

PROBLEM: Find the number of watts of energy expended in the circuit in Figure 6 when the e.m.f. is 120 volts and the current drawn by the lamp is 0.5 amp.

SOLUTION: The wattage for this circuit is computed as follows:

- | | |
|---|--|
| (1) Write the formula: | $W = E \times I$ |
| (2) Substitute known values: | $W = 120 \times 0.5$ |
| (3) Perform the work as shown at the right: | $\begin{array}{r} 120 \\ 0.5 \\ \hline 60.0 \end{array}$ |
| (4) Write the answer: | $W = 60 \text{ watts.}$ |

The number of watts may be expressed in the larger unit "horse-power", abbreviated "H.P." In terms of horse-power, one watt is equal to $1/746$ th of an electrical horse-power. This is equivalent to saying that one electrical horse-power equals 746 watts, or writing this in the form of an expression, we have

$$1 \text{ ELECTRICAL H.P.} = 746 \text{ watts.}$$

Another unit in common use is the "kilowatt". One kilowatt, abbreviated "kw", is equal to one thousand watts, or

$$1 \text{ kw} = 1000 \text{ watts.}$$

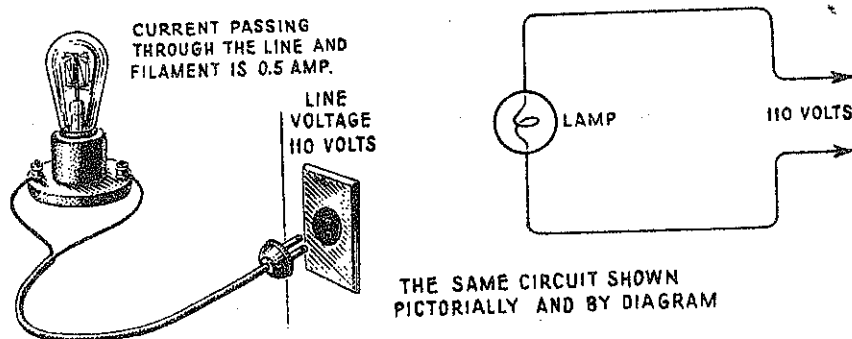


Figure 6

PRACTICAL USE OF WATTS FORMULA. The watts formula, for the law of power, can be stated in three ways as shown below for convenience in working out practical problems. Exactly similar relations are represented between the quantities in each of the formulas. An inspection of these formulas show that if the value of any one of the three quantities is unknown it may be easily found providing the other two quantities are known. Using the symbols, we have

$$\begin{aligned} W &= E \times I \\ \text{or } I &= \frac{W}{E} \\ \text{or } E &= \frac{W}{I} \end{aligned}$$

Another practical example in the use of the watts formula is worked out below.

PROBLEM: Let the rated power of a circuit be 660 watts and the line voltage 110 volts. What is the value of the current passing through this circuit?

SOLUTION: The formula is written first and the computation completed as follows:

- (1) Write formula: $I = \frac{W}{E}$
- (2) Substitute known values: $I = \frac{660}{110}$
- (3) Solving, we have $I = 6 \text{ amperes. Answer.}$

THE WATT-HOUR AND KILOWATT-HOUR. The watt-hour is a convenient unit to use in practical work for denoting the amount of energy expended in a given number of hours.

One watt-hour is equal to one watt of electrical energy expended in one hour.

The watt-hour is the unit of measurement that is applied in the calibration of electric meters installed in our homes, factories, office buildings and so on, for indicating the amount of electricity consumed; the meters used for this purpose are usually equipped with several dials for recording and are called watt-hour meters.

Since a watt is equal to a volt multiplied by an ampere, it is easy to see that watt-hours must equal volts multiplied by amperes and time; or stated in a formula, we have

$$\text{WATT-HOURS} = E \times I \times \text{HOURS}$$

In many cases the unit "watt-hour" is too small for practical computations, and for convenience a larger multiple of the unit is employed, called a "kilowatt-hour". Remember that one kilowatt equals 1000 watts. Therefore, a kilowatt-hour is found by first multiplying volts by amperes by hours, and then dividing the product found by 1000. From this we derive the following formula:

$$\text{KILOWATT-HOURS} = \text{KILOWATTS} \times \text{HOURS}$$

$$\text{or KW-HRS} = \frac{E \times I \times \text{HOURS}}{1000}$$

One kilowatt-hour is defined as the equivalent of one kilowatt (1000 watts) of electrical energy expended in one hour.

EXAMPLES OF HOW THE TERM KILOWATT-HOUR IS USED. Suppose that a generator in a power plant is kept in operation to furnish light and power for a factory. If the output of this generator indicates that one kw. of electrical work is maintained for one hour the factory will use 1 kilowatt-hour; or if 2 kw. is maintained for one-half hour ($2 \times \frac{1}{2} = 1$) the factory will likewise use 1 kilowatt-hour; but, if 4 kw. is maintained $2\frac{1}{2}$ hours the factory will use 10 kilowatt-hours.

ILLUSTRATING THE PROPER USE OF THE TERMS: POWER, FORCE, WORK and ENERGY. Let us refer to the drawing in Figure 7 where a team of horses are at work raising a heavy iron beam. This illustrates how force applied through a certain distance causes or tends to cause a body to be set into motion. In this instance, motion is actually produced because the horses are strong enough to perform the task imposed upon them. In this action the force might be defined as the physical exertion put forth by the horses in accomplishing the work. The capacity which these horses possess for doing work of this kind is the energy. (Note: The energy cannot actually be created, it is a natural condition existing within the horses.) The work done is the result of the force exerted, or power expended, by the horses in overcoming

any opposition or resistance which the load presents. The heavy iron beam is the load. The power is the rate at which the work is done, that is, whether it takes the horses 15 minutes, or 1 hour, or any given time to lift the load. The total work includes the power expended and the time.

In summarizing the foregoing facts we can say in a few words that the energy possessed by the horses was converted into mechanical pulling or lifting power. This gives us a good illustration of the laws governing the "conservation of energy". Conservation relates to the transference of energy from one state to another. There is nothing lost, practically speaking, in the transference of energy from one state to another so long as our purpose is fulfilled; that is, so long as the work we desire to be performed is actually completed.

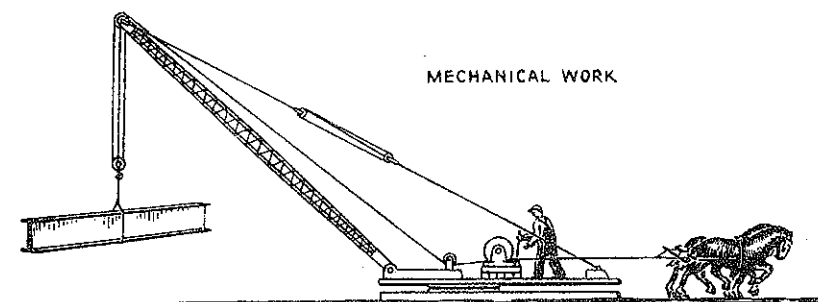


Figure 7

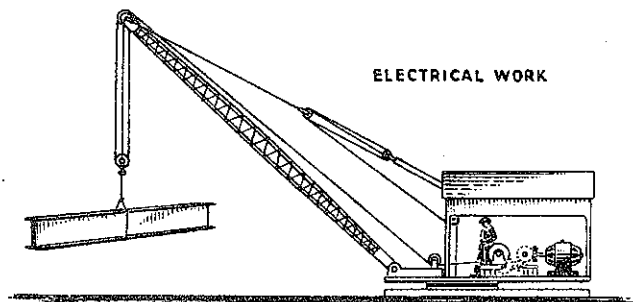


Figure 8

ELECTRICAL AND MECHANICAL HORSE-POWER DEFINED.

Mechanical H.P. In the illustration in Figure 7, we have shown two horses lifting a heavy iron beam by means of a hoisting crane. The power in this case is the rate at which the work of lifting the beam is accomplished. Mechanical work is measured in "foot-pounds" or "pounds multiplied by feet". Thus, if a weight of 3 lbs. is raised to a height of 5 ft. we have an equivalent of 15 foot-pounds of work. Suppose a $7\frac{1}{2}$ lb. weight is lifted only 2 feet we would have exactly the same amount of work done as when 3 lbs. is raised 5 ft., or 15 foot-pounds in both cases.

Now, to explain the meaning of mechanical horse-power let us suppose that the iron beam in Figure 7 weighs 33,000 lbs. and is to be raised one foot against the force of gravity, and suppose further that the horses take one minute to do this. Here we have a set of given values. Let us repeat them: 33,000 lbs is to be raised one foot in one minute. This combination of values is the basis for the rate of doing work which is equal to one mechanical horse-power. If twice this weight, or 66,000 lbs., is raised one foot in twice the time, or two minutes, the "rate of working" would still be the same as in the preceeding case, or one mechanical horse-power.

If the horses were replaced by a stronger team that could lift the same beam, the same distance, in just half the time, or let us say, in one-half minute, then it is logical to assume that one team is twice as powerful as the other. Thus, if 33,000 lbs. is lifted one foot in 30 seconds it would give us 2 mechanical horse-power. We see that both teams of horses perform exactly the same total amount of work, but, depending upon whether the work is completed in one hour, one-half hour or five minutes, or any other interval of

time, will determine the "time rate of doing the work", or "the power". Mechanical power is usually estimated in foot-pounds per minute, but in some practical work it may be more convenient to use foot-pounds per second. Thus:

$$\begin{aligned} &1 \text{ MECHANICAL H.P.} = 33,000 \text{ FT. LBS. PER MINUTE.} \\ \text{or} \quad &1 \text{ MECHANICAL H.P.} = 550 \text{ FT. LBS. PER SECOND.} \end{aligned}$$

We obtain the 550 in the lower equation, for expressing so many foot-pounds per second, by dividing 33,000 foot-pounds per minute by 60 seconds, that is, $33000 \div 60 = 550$.

In commercial practice the power is estimated according to the amount of work done in horse-power and the period of time involved in hours.

Electrical H.P. Electrical power is measured in watts, the measurements being based upon the second of time and not the minute which is chiefly used in mechanical work.

Let us suppose the horses, in Figure 7, are replaced by an electric motor as the source of power as in Figure 8. You will recall that power is estimated according to the amount of work done during a certain period of time. Accordingly, in our computations it will be necessary to know the amount of power that a motor is supplying and the length of time it is kept in operation.

In one of the paragraphs in this lesson, under the unit "Joule", it was explained that one joule per second is the unit of electrical power, or the watt. Furthermore, it was explained that the rate in watts at which electrical energy is expended is equal to the voltage of a circuit times the number of amperes of current flowing. Putting these statements together should give you an understanding of the significance of the watts formula; where

$$\text{WATTS} = E \times I$$

Also, from these statements it is a simple matter of deduction to determine that electrical horse-power is equal to watts divided by time, or

$$\text{ELECTRICAL H.P.} = \frac{\text{WATTS}}{\text{TIME}}$$

Where large amounts of power are handled it is often inconvenient to use a unit as small as the watt, as we previously mentioned, and so in the practical work of rating electrical machinery the larger unit "electrical horse-power" is employed. It will be recalled that one electrical horse-power equals 746 watts.

Now, in order to find the rating of an electrical machine, in the unit of horse-power, we have simply to know its capacity in volts and amperes; to find the horse-power multiply the volts by amperes and divide by 746. This is the same thing as saying that the number of watts are divided by 746. Hence, we have.

$$\text{ELECTRICAL H.P.} = \frac{\text{VOLTS} \times \text{AMPERES}}{746} = \frac{\text{WATTS}}{746}$$

The following worked out example is given to aid you in solving problems of this kind. The results can be expressed either in the unit watt, kilowatt or electrical H.P.

PROBLEM: Suppose the current drawn by the motor in Figure 8 is 20 amperes and the line voltage is 220 volts. Find the number of watts of energy consumed?

SOLUTION:

(1) Write formula

$$\text{WATTS} = E \times I$$

(2) Substitute known values: $\text{WATTS} = 220 \times 20$

(3) Solving, we get

$$\text{WATTS} = 4400 \text{ watts. Answer.}$$

If we wish to express the above answer in horse-power maintained by the motor, simply divide 4400 by 746, or

$$\text{ELECTRICAL HORSE-POWER} = \frac{\text{WATTS}}{746} = \frac{4400}{746}$$

Hence, $\text{ELECTRICAL HORSE-POWER} = 5.8 \text{ H.P. Answer.}$

This answer expressed in kilowatts is $4400 \div 1000 = 4.4 \text{ kw.}$

THE BASIS OF COMPARISON BETWEEN MECHANICAL AND ELECTRICAL H.P. The basis for comparing an equivalent amount of mechanical energy measured in "foot-pounds" and electrical energy in "watts" was worked out mathematically many years ago by Dr. Joule. He made a direct comparison between both kinds of energy in performing exactly the same work which consisted of heating a given quantity of water until its temperature was raised to a certain value. In the case of mechanical energy the heat was obtained from the friction set up when paddle wheels were rotated through the water. The amount of power required was figured from the number of foot-pounds of work per second obtained from a certain arrangement of pulleys and weights used in the experiment. In the case of the electrical circuit the power was computed from the amount of current consumed at a certain voltage and the time required in generating the specified amount of heat. Dr. Joule estimated that 1 foot-pound per second = 1.356 watts.

We have already given an equation which states that 550 foot-pounds per second is equivalent to 1 mechanical horse-power. The electrical equivalent of this, or 1 electrical horse-power, would be

$$1 \text{ ELECTRICAL H.P.} = \frac{550}{0.7375} \text{ or } 746 \text{ watts.}$$

THE METER is the unit of measurement for wavelength. Wavelength can also be expressed in terms of frequency. These terms are used in connection with electromagnetic wave motion in space, by this we mean radio waves in space. The terms can be interchangeable, it being a simple matter to convert wavelength to frequency and vice versa. This is explained in a subsequent lesson. Refer to Figure 9, which shows a regularly recurring wave motion set up on the surface of water by striking it with equal intensity at regular intervals with a wooden block.

The term wavelength can best be explained with the aid of a drawing of this kind and after once understanding the meaning of wavelength it can be applied to any form of motion that occurs and reoccurs at regular intervals.

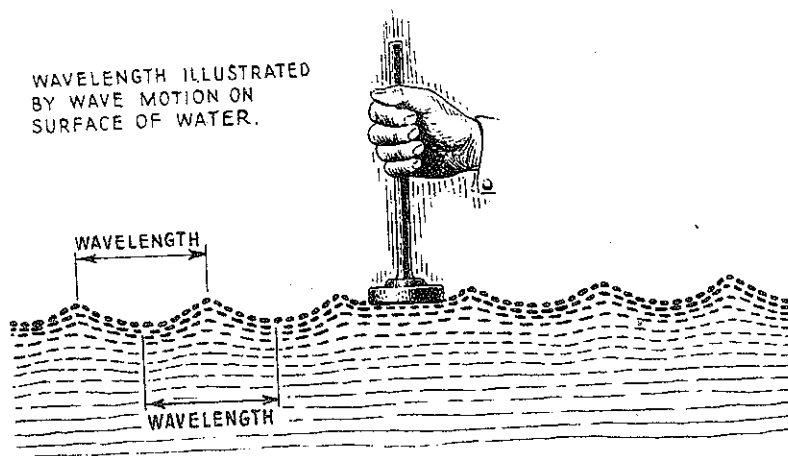


Figure 9

One wavelength is the distance from crest to crest of the wave in Figure 9, or it may be the distance from trough to trough, which naturally would be the same. Moreover, we could consider any point on one wave impulse and compare it to a similar point on an adjoining wave impulse and say that the distance between these two selected points is one wavelength. Let us try to visualize a wave motion occurring in space, set up by unseen forces. Suppose that an electromagnetic wave is projected from an active transmitting antenna and this energy consists of a succession of rapidly recurring impulses in space, due to the disturbance set up in the space medium. The length of each individual wave or complete impulse of the electromagnetic wave motion is considered from a similar viewpoint as each water wave.

The metric unit of measurement is used to compute such distance. Thus the wavelength of an electromagnetic wave sent out by a radio transmitter may be 300 meters, or it may be 1,500 meters or 14.5 meters or any desired length which is governed by the electrical adjustments of the transmitter. One meter equals 39.37 inches. The student must not confuse the distance which a radio wave will actually travel to be intercepted and heard in the receivers (which may be several thousand miles in some cases) with the wavelength of each individual impulse in the complete wave motion.

EXAMINATION - LESSON 2

1. Give the definitions of the following units, expressing them in your own words. Do not use the exact wording given in the lesson.

(a) volt	(d) coulomb	(g) farad
(b) ampere	(e) watt	(h) kilowatt-hour
(c) ohm	(f) henry	(i) ampere-hour
2.

(a) What is a megohm?	(d) Micro-microfarad?
(b) Microhm?	(e) Microfarad?
(c) Kilowatt?	
3.

(a) Can energy be created?	(c) What must we first have in an electrical circuit before current will flow?
(b) Name two practical sources for obtaining electrical pressure.	(d) What unit of time is electrical measurement based on?
	(e) How would you write 35 mmfd in the unit mfd?
4. Suppose the capacity of a generator when carrying a load is 3500 watts. Express this value in kilowatts and horsepower.
5. What is the difference between work and power? What is force and energy? Use an analogy, if you wish, in order to explain the meanings.
6. (a) Write the formula you would use if the power and current of a circuit were known and you were asked to find voltage.
(b) Write the formula you would use to find current strength if the voltage and wattage of a circuit were known.

Note: Solve the following problems which relate to direct current circuits. Use the form suggested in worked-out examples in this lesson where the formula is written first, the known values substituted next, and so on.

7. If 3 amps. passes through the lamp in Figure 6, and the line voltage at the wall outlet is 110 volts, what power is being expended?
8. Suppose an electrical heater, rated at 350 watts, is placed in operation and by measuring the current strength with an ammeter, we find it to be 3 amps. Find the line voltage.
9. If the load on a generator supplying an electrical circuit is such that a current of 200 amperes flows at a pressure of 120 volts, what is the capacity of this machine in watts? Also, in kilowatts?
10. In this problem you are given the following data: The e.m.f. is 120 volts, the current drawn is 20 amperes and the generator is maintained in operation 12 hrs. Find kilowatt-hours of energy expended.